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THE AUSTRALIAN METEOROLOGICAL ASSOCIATION

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EDITOR'S NOTE :

Contributions in the form of letters or articles by readers are most welcome.

Australian Fisheries Leaflet. No. 3.

Use of Drift Bottles in Fisheries Research

By D. Vaux and A. M. Olsen

CSIRO Division of Fisheries and Oceanography

THE lives and habits of fish are so closely linked with, and dependent on, physical conditions in the sea that no rational study of fish can be undertaken, much less achieve meaningful results, without exhaustive inquiry into the environment in which they live. Water movements affect the occurrence and distribution of the food of fish, the migrations of fish, and the dispersion of their eggs and larvae; consequently knowledge of these movements is essential for the understanding of annual variations in abundance of many species of fish as reflected by the relative success or failure of the commercial fisheries.

HISTORY OF RESEARCH

Research into the physical, chemical, and biological aspects of the environment of fish has been undertaken only recently in comparison with research in other fields of science. In 1899 representatives of half a dozen European governments met at Stockholm to discuss the study of the seas, and in particular of hydrography in relation to fisheries, of the fisheries themselves, and of the biology of the various species of fish. In a review of 50 years of fishery biology in Europe, Michael Graham, director of fisheries research in England for many years, discusses the work of several pioneers in these subjects and says:

"The requirements seen by the delegates at the Stockholm conference stand out as three. There was considerable need for improvement and standardisation of methods, especially in hydrography. Next, the delegates evidently thought that the isolated workers had not yet given sufficiently full descriptions either of the hydrography or of the biology of fisheries, and they planned a very full programme of observations at sea. Thirdly, they considered that the time had come, or was coming very soon, for international regulation of the fisheries in the general interest, and they saw the need of joint consideration and discussion of the best means for bringing this about." . . .

"Victor Hensen had conceived the possibility of evaluating the production of the sea by sampling the plankton with nets. Frank Buckland had devoted a life's work to the conception of managing fresh-water fisheries according to their natural history. T. W. Fulton had started to relate hydrographical studies to the facts of commercial fisheries whilst E. W. L. Holt had done the same for biological studies, and had advocated remedial measures for the North Sea plaice.

Fig. 1.

Fig. 2.

Particularly eminent among these pioneers was C. G. J. Petersen, who had correctly appraised the problem of rational exploitation of a fishery and had also demonstrated the possibilities of transplantation to areas with a rich bottom fauna. On the hydrographical side, Otto Pettersson had sketched the possibility of relating fluctuations in fisheries to astronomical phenomena through hydrographical effects, and so of foretelling them. Fridtjof Nansen had begun the study of water masses, and Martin Knudsen investigated the chemical and physical characteristics of sea water. These names may serve to indicate the kind of discoveries that had already been made when the conference met in 1899."

A second milestone in the history of fishery research was the inaugural conference on the "Conseil International pour l'Exploration de la Mer" in Copenhagen in 1902.

STUDY OF ENVIRONMENT

The earliest observations in this field of research followed Professor Edward Forbes' theory of 1843 that life in the sea probably ceased to exist at a depth of about 300 fathoms. Below that lay the "azoic zone," destitute of organic life. By 1869 exploratory cruises by H.M.S. Lightning and H.M.S. Porcupine had shown that life existed to depths of 2,500 fathoms at least, and that the sea's temperature, previously thought to attain a constancy of 4°C (the maximum density point of fresh water) dropped to between —1° and —2°C.

Movements of Water

Since these early discoveries, the temperature of the sea has been the most widely studied characteristic in relation to its biological implications. Another property much used in hydrography is the salinity, or "salt content" of sea water. In combination with temperature values, salinity figures give important information to scientists on the movement of water in the oceans.

The study of currents is of primary importance in fishery research. Most fish have eggs and larvae which float freely in the water and are carried passively by the currents. The fate of recently hatched fish depends very largely upon where they are carried, and it is possible that the large variations in abundance which occur in most fisheries may be linked to changes in the course of the currents which affect the distribution of the fry. The larger fish seem to be guided in their feeding or

DRIFT BOTTLE No.....0850

Where was this bottle found? .....

Amount of growth on bottle—None, Slight or Heavy.
Condition of growth on bottle—Alive or Dead.

On what date .....

Name and Address of finder .....

Please fill in the above particulars and mail this card.
A Reward is given for its return.

(Commonwealth Scientific and Industrial Research Organisation, Australia—Hydrographic Investigation)

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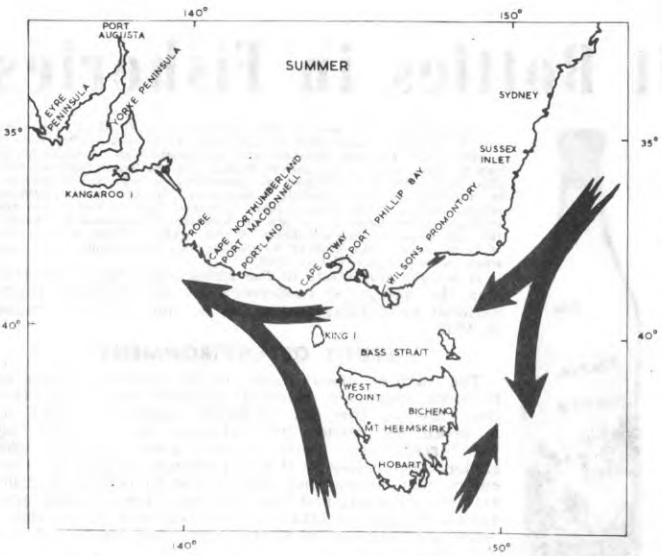


Fig. 3. Drift of surface water in summer on basis of drift bottle recoveries.

spawning migrations by currents; most fish move up-current towards their spawning places from which the eggs and larvae are distributed down current.

HOW WATER MOVEMENTS ARE STUDIED

Direct research on water movements in shallow seas is carried out by two methods. Current meters, which are similar to the apparatus employed by meterologists to measure the rate and direction of wind, may be used. An alternative is to use drift bottles, or drift cards, thrown into the sea in large numbers, and this method has been widely used, and is still in use, in Australian waters.

Drift Bottles

Bottles have been used in the past for conveying messages from vessels which have met with disaster on the high seas, but in these days of improved communication, most "bottle-post" papers or cards will prove to be documents originating from a research institution whose concern is the investigation of currents in the great oceans or the shallow seas. A considerable amount of knowledge has been gained from the movements of derelict vessels and wreckage, and of icebergs, but the wind exerts much influence on the movements of objects only partly submerged.

An illustration of this is given in the case of the American schooner Fred Taylor, which was cut in two by a German liner in 1892 at a spot 260 miles south-east of New York. The after part of the vessel, which floated well out of the water, was driven north by the wind, whereas the foreward part, lying deep in the water, was carried south by the current. A floating object must ride very low in the water before it can be taken as a reliable indicator of current.

Types of Drift Bottles

A simple drift bottle (**Fig. 1**) consists of a glass bottle containing a questionnaire paper or postcard, ballasted with sand so that it floats with just a fraction of its neck out of the sea. The postcard (**Fig. 2**) contained in the bottle bears a number by which the investigator recognises the date and place of its liberation. The finder is asked to give information on time and place of finding and to note whether there was any growth on the bottle. During the time of the bottle's sea drift, animals such as the "goose" (or stalked) barnacle sometimes attach themselves to the bottle, and as these animals die soon after removal from the sea, the condition of any growth on the bottle may indicate how long it has been ashore. A reward of 2/- is offered for information on each bottle found.

In addition to the postcard, each bottle contains a brightly printed card to attract attention. The original words "Break this bottle" were replaced by "Please remove this card" in an attempt to avoid danger from broken glass on beaches.

Various materials have been used for ballast. Sand is cheap but it has to be completely dry to avoid damage to the cards enclosed with it, and crushed blue metal (dolerite) from one of Hobart's quarries is preferred for Tasmanian drift bottles. Being denser than sand, less is required for each bottle.

Allowances have to be made for the differing densities of sea water in which the drift bottle may travel; a bottle which just floats in fresh water with its top awash would float in sea water with about two inches of its neck exposed to the wind. In order to overcome the effect of the wind and to make the drift bottles represent the movement of water just below the surface, metal drags have been attached to bottles by a wire about three feet long. The use of these two types of bottles together gives some idea of the effect of wind on water movements and the indication of the existence of a velocity gradient in the upper layers of the sea.

A third type of bottle has been used to obtain information on the currents near the sea bed, for these are the currents which might be expected to affect bottom-living fish such as plaice and flathead. This type of bottle is weighted so that it will sink in sea water, but in order to keep it just off the bottom, it is fitted with a stiff wire tail. When such an object is thrown into the sea, it sinks gently to the bottom and, remaining lightly raised on its tail, should be moved easily along the bottom by the currents there.

Recent investigation by scientists equipped with underwater breathing apparatus has shown that although these bottles do move, the movement is much less than that of plankton and other suspended material which can be seen floating past these bottles. Improved bottom-trailing "bottles" can be made with some of the plastic materials now freely available, but use of such types is limited in any case to areas where concentrated trawling will ensure adequate returns of the devices.

The bottles already described afford information on the position of recovery only, and the actual route may be quite different from

the shortest line between points of release and recapture. Bottles which sink after varying time intervals and anchor themselves have been used on occasions, but these too depend on their recapture by trawlers and can be used only on heavily fished grounds.

Drift Cards

Another variation of these floats was made by F. C. W. Olson, who used postcards sealed in polythene envelopes in his studies on Lake Erie in 1950. Under the conditions of his experiments "drift cards actually indicate surface flows, and are not at the complete mercy of the winds." However, a comparison of similar drift cards with surface drag-fitted bottles led English scientists to abandon the use of cards as an indication of where fish eggs and larvae, distributed throughout the depth of the water, would be carried by residual currents. They are occasionally used for specific experiments, such as the study of pollution in the sea by oil waste, where an estimate of the surface drift is required.

Drift Bottles in Special Projects

The liberation of large quantities of drift bottles over widely spread areas in order to "see what happens" is a temptation which the investigator must resist. Although bottles which have been at sea for long periods and have covered many thousands of miles are undoubtedly of interest, an accurate interpretation of their drift is impossible, and it is usually the bottles which have been adrift for only short intervals of time in which the hydrographer is interested. To simplify the interpretation of results the period of liberation of bottles is usually restricted to a specific period in the life cycle of the fish on which interest centres; this is usually the spawning period and a short time immediately afterwards. If this period coincides with the time when beaches are most populated, a drift bottle programme will have a better chance of being effective than if the beaches at that time are deserted.

Drift Bottles in Tas. and South Australian Waters

The only drift bottle programme at present in operation by CSIRO Division of Fisheries and Oceanography is one undertaken in Tasmanian and South Australian waters, which is part of a broader programme designed to study the life history of the marine crayfish. About October in each year

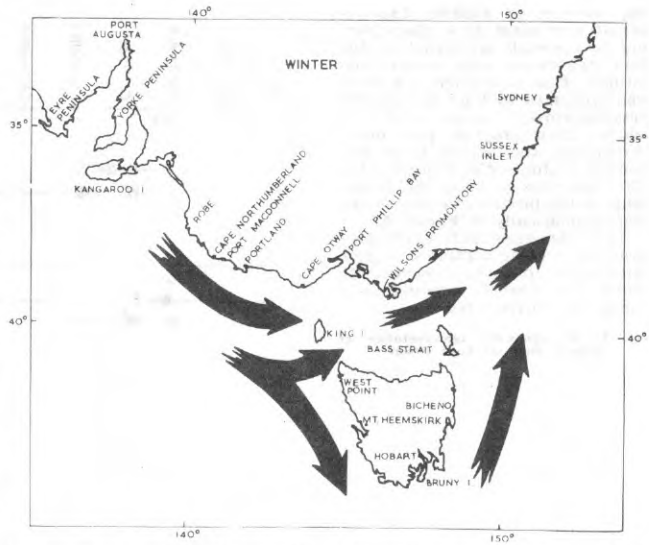


Fig. 4. Drift of surface water in winter on basis of drift bottle recoveries.

the eggs of the crayfish hatch into small larvae quite unlike the adult animal. These larvae seek the surface waters, and, as far as is known, remain there for about 4-6 months, and during this time they are carried by surface currents. As it is not possible to mark the larvae, indirect methods such as drift bottle releases have to be used to study the water movements which may distribute the crayfish young.

Since the programme began in September 1858, over 4000 bottles have been released from co-operating commercial vessels in monthly batches of 50 from each of the four positions (**Figs. 3 and 4**):

(1) Abeam of Mt. Heemskirk, Granville Harbour, Tasmania.
(2) Abeam of West Point (Western Tasmania).
(3) Approximately 30 miles southwest of Cape Otway, Victoria.
(4) About 8 miles south of Cape Northumberland (South Australia).

Since January 1960, unballasted and ballasted bottles have been released together from the position off Cape Otway to assess the effect of wind on drift bottles.

Drift bottles have been picked up over a wide area after periods of liberation ranging from two days to 18 months. From Cape Northumberland bottles have drifted ashore on Eyre and Yorke Peninsulas and Kangaroo Island (South Australia), to Wilson's Promontory (Victoria) and Sussex Inlet (New South Wales). Bottles from Cape Otway have been returned from Yorke Peninsula to Port MacDonnell (South Australia) around the Victorian coast, including Port Phillip, to Sussex Inlet and Sydney (New South Wales), and at Bicheno (Tasmania). Mount Heemskirk bottles have travelled to King Island, Portland (Victoria), Robe and Yorke Peninsula (South Australia). Two bottles released from this position on November 3, 1958, stranded within half a mile of each other on South Bruny Island after being carried by currents south of Tasmania, but the first was found on November 17, after covering about 180 miles in the 14 intervening days, whilst the second was not picked up until February 21, 1960, some 15 months later.

Results from the first two years of drift bottle releases confirm earlier ideas of water circulation in these areas during winter months but variations in this pattern during summer have been noticed. The water movement along the coast of South Australia in autumn, winter, and early spring is usually southward towards Bass Strait, with branches flowing south along the western coast of Tasmania and east through the Strait; these movements were reversed during the summer of 1958-59. In the follow-

ing summer of 1959-60, this reversal movement took place during two periods separated by the flow associated with winter conditions. This anomalous condition was confirmed by Port MacDonnell crayfishermen accustomed to leaving their crayfish pots down throughout the season from November to June. Water movements off Cape Otway since the beginning of the programme are shown diagrammatically in **Figure 5.**

The Tasmanian drift bottle programme is being continued to give information on water movements under the varied meteorological conditions encountered.

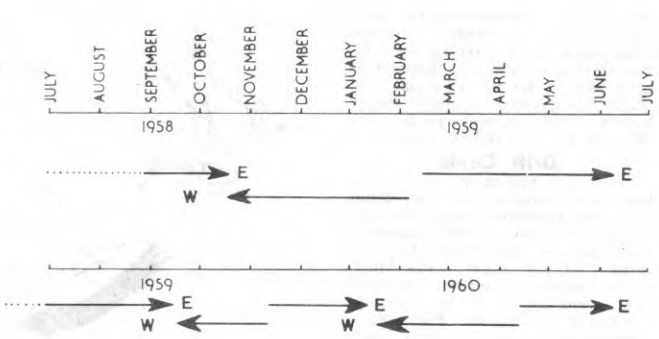


Fig. 5. Diagrammatic representation of surface drift off Cape Otway.

ASTHMA RESEARCH

Biometeorology

by J. Hogan

The Bureau of Meteorology was asked by the Asthma Foundation in South Australia to assist in determining if there is any relation between weather and asthma.

I, personally, have no pre-conceived ideas on the matter, but after long experience with asthmatics in my own family I have had a very great interest in the subject, and this project gave me the opportunity to assist in finding out if there is any real relation between weather and asthma.

A number of patients were selected, with wide variations in location, age and types of asthma, and these report their asthmatic condition daily on specially prepared forms. At the same time, the Bureau is recording special weather observations, and these and the reports from the patients are placed on punched cards for later statistical analysis by computer.

CLIMATE AND WEATHER

It is known that asthmatics react to:-

dust
pollens
spores
ingestants
mental stress,

but it is not certain what part the weather plays. Much investigation has been carried out and many theories propounded, but few positive conclusions have been reached.

In speaking of weather two aspects must be considered:-

(1) climate
(2) day-to-day changes.

Some asthmatics may respond favourably to a change in climate. Some respond to a coastal climate and others to a transfer away from the sea. What needs to be determined, however, is whether it was the change in climate that was responsible, or whether it was the result of moving away from a local source of allergens, or the micro-climate in the home - the airconditioning system or the heating system.

CANBERRA

It is generally believed that asthmatics in Sydney react favourably to a climate like that experienced in Canberra.

Consider this variation in climate:-

Canberra:

Higher altitude therefore lower pressure (a test on an arthritic patient by lowering the pressure produced an asthmatic attack).

Colder in winter.
Warmer in summer.
Lower relative humidity.
Different prevailing winds.

The problem is to determine which, if any, of these elements or combinations of elements is responsible.

Sydney is close to the sea so it is possible that the salt content of the air is deleterious. It also has more pollutants in the atmosphere and a much higher tempo of living, which could also contribute to the problem of the asthmatic. It could in fact be the removal of one or more of these factors and not the climate which is responsible for the improvement.

DAY TO DAY WEATHER

Most asthmatics seem to agree that they do react to changes in the weather, particularly sudden changes from warm or mild to cold, windy weather. The question which arises from this is whether or not they all respond in the same way to each change and it seems that the answer is that they do not.

Tromp states that the thermo-regulatory system of the body breaks down in cold weather. He has also found that there is a correlation between the passage of cold fronts and asthma incidence - decreasing with successive fronts.

PRE-FRONTAL WEATHER

Perhaps it is that certain weather conditions prior to a change are conducive to the rapid growth or release of certain spores or pollens. However it may be that same are only released under certain weather conditions, as is the case with one particular type of spore which requires impact by large rain drops for its release or, what is known as "splash dispersal".

It could be that it is the prevailing wind for some time prior to the change which is responsible for the transport of pollens and spores or dust from remote localities, and that their concentration is greatest about the time of the change, and so it may not be the change itself which produces the attacks. They may be due to a delayed effect of the pre-frontal conditions.

Some pollens which are known to cause asthma are not produced in the metropolitan area. Their source is at present unknown.

TEMPERATURE

Some overseas and some Australian workers in this field have found a correlation between asthma and temperature. Temperature however is generally directly related to wind strength, direction and trajectory, so it may be the wind itself or the wind-borne pollen from a particular direction which is the controlling factor and not the temperature.

CARS AND FACTORIES

The variation in the production and distribution of gases and pollutants from motor vehicles and factories are other factors which could be irritants even if not the cause of asthma, and their concentration is partly dependent on weather conditions. Calm conditions are responsible for an increasing density by settling, and windy, turbulent conditions for wider scattering.

IONS

Another factor which may or may not have some effect on asthmatics is the presence of small, electrically charged particles in the atmosphere known as "ions". These have positive and negative charges, the latter being partly composed of oxygen and the former of carbon dioxide.

THUNDERSTORM EFFECTS

Variations in atmospheric conditions, particularly thunderstorms, are responsible for rapid variations in the amounts of both types of ion. Some overseas investigators have found that persons subjected to a stream of negative ions improved considerably - the conclusion being that the oxygen gave them a lift. In another case people taking an examination during a fierce thunderstorm showed not a lower pass mark, as might have been expected, but considerably higher than in any previous exam.

It is obvious that at present we don't really know what particular element or combination of elements in the atmosphere is responsible for the physiological changes in humans. It is only by conducting a thorough investigation of the type proposed that we may be able to eliminate perhaps a few of the suspected causes. It may be that some correlation may be found between one or more of the weather elements and therefore the causes of some types of asthma.

Even if the conclusion is that there is no association between the incidence of asthma and the weather, we will have achieved something of very great importance, as it will then be necessary to look elsewhere for the answer.

We are not over-optimistic, we are just hopeful that we will be able to help.

ASTHMA RESEARCH

THE HOUSE DUST MITE - DERMATOPHAGOIDES SPP

The Housedust Mite has been the medium of an extensive study sponsored by the Asthma Foundation of South Australia Incorporated. The survey of its population fluctuations and its relationship to bronchial problems in patients has included regular weekly sampling of 8 houses in the metropolitan area of Adelaide.

Data for the first year are now analysed and there is a strong coincidence between the peaks of mite population and the peaks of bronchial problems in most patients. Some patients have not provided adequate data on their attacks or potential attacks, and others are not sensitive to the Housedust Mite. The latter are study controls.

In general there are three distinct peaks in the mite population. These vary slightly in time from house to house, but usually there is a large peak in mid-summer (December), a smaller peak in mid-winter (June) and a still smaller peak in autumn (March). In typically mite-sensitive patients, a significant increase in the number of days per month on which attacks occur or increased medication is necessary, begins to appear a few days following increase in the mite population and declines a few days after the density of mites decreases.

There are two species of these mites found in South Australia, *D. pteronyssinus* and *D. bakeri*, the latter being less common in samples taken so far. They feed on human skin flakes, exudates from sebaceous glands and other substances such as scabs, dried blood and some plant materials. They are associated with various mammals and with birds. They are tiny, about 0.2 mm long, and may float in the air following the raising of dust during house-cleaning or the making of beds.

In the present survey large numbers of mites have been found in some patients' beds, at times which coincide roughly with increases in the populations of living room carpets. It is thought that some patients may be reacting to population fluctuations of the mite in their beds rather than to those in the house as a whole. This is particularly so where the numbers of mites from beds greatly exceed those from floors.

Dermatophagoides spp. and their excretions are irritants when in contact with the skin or mucous membranes of susceptible people. The allergen has been isolated from *D. pteronyssinus* and has been used to demonstrate hypersensitivity in susceptible people. It is useful also in determining whether people with bronchial disorders are allergic to the mites or not.

The life history of these mites is not well known. The eggs are colourless and round and hatch in about 4 days. Usually one or two nymphal stages follow, and females may be fertilised prior to becoming adult. The life cycle may be completed in as little as two weeks, and continuous breeding is general resulting in about 20 generations a year. All stages of the mite are able to be found in each week of the year. They may be reared on various plant materials but respond better if human skin-flakes are included in the diet.

From the experience gained in this study it is apparent that the mites spend much time in various parts of the house. They probably also occur on people and in their clothing at all times. Some species have been known to exist for relatively long periods in unused cotton

bedding. Their control or eradication thus seems extremely difficult.

Houses with high levels of hygiene may still support large populations of mites, and sampling sites with high yields of dust do not necessarily have the highest numbers of mites. Often the reverse is the case. Complete vacuum cleaning of electric blankets at 14 day intervals has failed to prevent enormous increases in the mite population over these time intervals. Pressing the blanket with a hot iron and airing in the sun have likewise had no apparent effect on resident mite populations.

Weekly cleaning of beds, bedding and houses, while not preventing expected fluctuation in mite populations, is nevertheless the basis of control procedures. Oiling of bedding by spraying a fine mixture of paraffin wax in white spirit on to linen and blankets to provide a thin layer not detectable to the touch may assist in reducing the dust usually produced when making beds. Note that rubber mattresses and pillows should not be sprayed with this mixture.

Under-blankets should be discarded and plastic or rubber sheeting substituted if desired. Vacuum cleaners should be tested at least once a year to ensure that their performance is adequate. Empty the vacuum cleaner outside the house but away from open windows or doors. Always try to ensure that dust collected is removed completely from the house.

No acaricide for use throughout houses has as yet been tested and found to be effective for reasonable periods without causing some risk to householders. Dusts or sprays containing Lindane have been recommended in North America where control of dermatitis and bronchial problems attributed to this group of mites has been largely unsuccessful so far.

NEW GUINEA REVISITED

by J.C. Tolley

I first went to New Guinea during the 1939-1945 war and was stationed in a number of areas throughout the Territory. I consider myself lucky in that I have been able to pay two return visits. The first was in 1963 when I covered some of the places I saw during service. One area I could not visit because of lack of time was Eastern Papua.

However in June 1972 I was able to make another visit and this time, thanks to friends in the area, was able to travel through some of the Milne Bay area and call at a few of the adjacent islands.

This area is fairly remote and away from the usual places visited by tourists, which made it all the more interesting. To get to Milne Bay necessitated a trip of 1½ hours in a DC3 travelling east from Port Moresby to one of the old wartime airstrips at Guerney on the shores of the bay.

From here I was picked up by launch and taken to Sideia Island east of the entrance to Milne Bay. Sideia is remote. There are no airstrips, as is the case with all of the places visited in this area, and can only be reached by sea. The natives are still primitive and you can form some idea of how these people lived before the coming of the White Man. It was a good time of the year to visit Papua New Guinea because during the so-called dry season the humidity is much lower and temperatures reduced, making conditions more bearable than during the wet season. Nevertheless, it can still be fairly uncomfortable. Rainfall on Sideia Island averages some 120 inches per year, spread fairly evenly throughout the twelve months.

One particular place visited was the island of Samarai. This island, only 59 acres in area, is in the China Strait right on the eastern end of the Papuan mainland. It has a very interesting history. It first appeared on the map in the 1880's when it was developed as a supply base for the first Papuan gold field discovered on Misima Island further to the east among the myriad islands and coral reefs that abound there. From this beginning as a trading post, the island grew in importance as a centre and, because large ships travelling through the China Strait could berth in safety for the discharge or loading of cargo, it was eventually made the Headquarters for the Milne Bay District. Because of its small size it takes only 20 minutes to walk around it. With the increasing number of Government Departments being established there, it has become very overcrowded. Moves are now in progress to transfer the Headquarters to Alotan on the northern shore of Milne Bay, where there are suitable areas for expansion. Until the large influx of population, Samarai was described as being one of the most beautiful islands in the South West Pacific. Perhaps with a reduction in the population this state may return. The climate is pleasant although humid for most of the year. An average rainfall of 108 inches per year usually ensures an adequate fresh water supply.

Another island I visited was Normanby Island, north east of Milne Bay. The southern coast of this mountainous, sparsely populated island has an estimated annual rainfall of 300 inches per year. No official records have ever been kept. The narrow coastal strip is populated, but in the interiors, parts are still unexplored. The northern section of the island is volcanic and on the south coast a

small river discharges very hot water into the sea. The hot water evidently originates in some subterranean thermal activity connected with the volcanic area.

Sewa Bay, situated on the south coast of Normanby Island, is an excellent shelter for shipping. An island conveniently placed across the opening from the sea leaves only one small but deep channel for shipping to enter the huge area of calm water. Ships of 10,000 tons can enter in safety and once inside they cannot be seen from the sea. Because of this the Bay was known as Hidden Harbour during the First World War when it was a Royal Naval Base. The Japanese used Sewa Bay during the early part of the South West Pacific Campaign, but Allied aircraft caught some ships in the Bay and cancelled out its descriptive name, as bestowed between 1914-1918. Today there is little activity in the area, with only one sawmill operating. Timber has been loaded onto large Japanese freighters that called into Sewa.

Basilaki Island, east of Milne Bay, was another place visited. This is another most primitive area with very little evidence of White Man's influence. There are a number of beautiful small bays with white, sandy beaches and ringed with coconut palms along the coasts. Fish abound in the waters and there is a vast collection of beautiful shells just waiting to be picked up, along these tropical shore lines. Basilaki Island could be considered more truly representative of the South Sea coral island than most places today.

In all my travels in this eastern area of Papua I covered over 300 miles by sea, and even then I only visited a few of the many islands comprising this area of the Territory. Sea travel is the only way. There are no air services as there are no landing strips on these islands.

On my return to Port Moresby, I travelled by way of Goodenough and the Trobriand Islands. The former island is as mountainous as the latter group of islands. The highest peak on Goodenough reaches over 8,000 feet, while in the Trobriands the high spot is under 200 feet above sea level.

The Trobriand Islanders are an interesting, separate ethnic group. They have descended from different stock and have a separate culture and customs. The islanders are great carvers and produce interesting designs from local timber and a black ebony-type wood, which has to come from outside sources. Lately they have become so engrossed in their carving for the tourists, who are calling in at the islands in increasing numbers, that they are neglecting their gardens. The consequent food shortage has been the cause of some trouble to the Administration.

Having called in at Port Moresby for a short time, I then left to fly across the Papua New Guinea backbone, the Owen Stanley Range, to New Guinea where I visited friends in Lae.

This town is a fastgrowing place which has been completely rebuilt since the war. All amenities are available and gardens, lawns and parks abound. There are many modern homes. The humid climate is not improved with the 180 inch rainfall, but it does keep the whole town area green for nearly all of the year. Walking down the main shopping area, one could be excused for thinking they were in a large country town anywhere in Australia except, of course, for the oppressive climate.

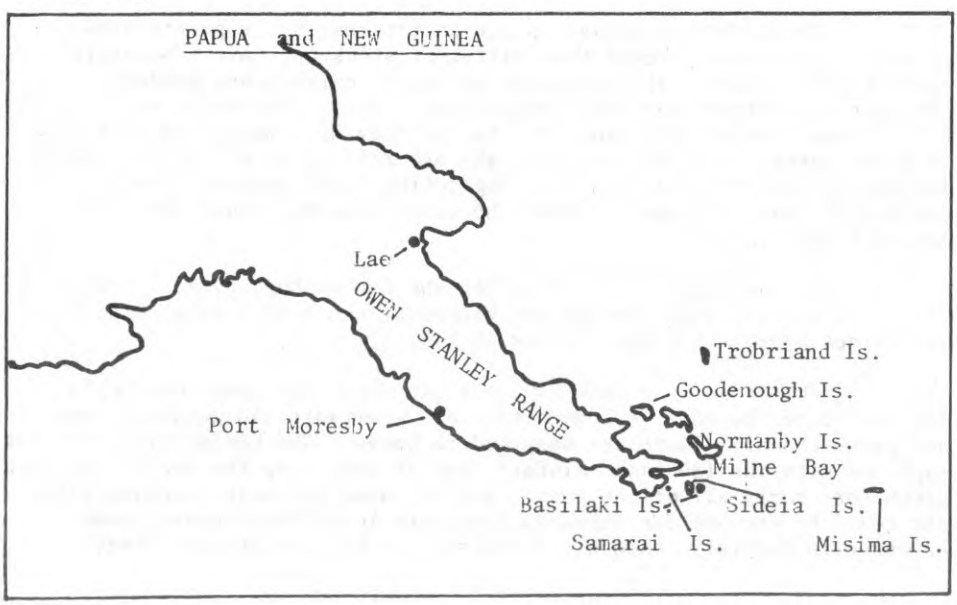
I returned to Port Moresby from Lae, flying at 13,000 feet and looking out at mountain peaks on the same level as the plane was flying. Looking below into the green, rugged terrain, you cannot help thinking of the consequences of engine failure in such an area. The chances of getting out, let alone being found, would be remote.

Port Moresby in June is as brown and dusty as Lae was green and moist. A town with a rapidly growing population of now upwards of some 70,000 people, it is a busy place. All amenities are provided. There is a public transport system to connect the outlying suburbs spread out between the bare, brown hills not unlike parts of the Adelaide Hills in mid-summer. Electricity is available from hydro electric sources on the Laloki River and water is piped to most homes. The rainfall of only 40 inches per year is in contrast with most parts of the Territory. This falls mainly in the period November to February and the rest of the year is mostly dry. Thus the dust and dry foliage in June.

Administration of Papua and New Guinea is centred in Port Moresby and there has been much rapid development in the establishment of the various Government Departments in the suburb of Konidobu, which is close by Moresby itself. The expansion in this area has quickened recently with the forthcoming self-government and the independence promised in the future.

I left Port Moresby at 1 pm in a temperature of about 80°F and fairly high humidity to fly home. By 8.30 pm on the same day I was at Adelaide Airport with the thermometer on 48°F and it was cold and wet.

During the return flight I had time to reflect on my good fortune to have been able to look at New Guinea and Papua in peace time and to contemplate what may be the outcome of this fast-emerging country. You cannot but wonder how these natives will be able to cope with today's problems of civilization and just what will be the end result. But whatever happens, events in the Territory must affect us here in Australia and for this reason we should follow developments carefully and closely.



AN INVESTIGATION OF WEATHER CYCLES

by G. O'Mahony

1 INTRODUCTION

A question which most people have asked of themselves from time to time, and which is invariably asked of all meteorologists is - "How reliable are cycles of weather?".

The question as it stands does not admit of the simple answer, not because we wish to be vague or non-commital, but rather because its meaning is not sufficiently precise. For example it is a matter of common experience that there is a definite seasonal cycle in weather, and so we could make a general prediction and say that it will generally be hot and dry in February and again, that it will be cold in July. On a smaller time scale also, we are all aware of the diurnal or daily changes in weather, as evidenced for example, how the maximum temperature usually occurs early in the afternoon, and how the minimum temperature is generally recorded about dawn.

These examples are so obvious that they may be classed as trivial in the present context, so our question must have a deeper significance. Let us interpret the question and allocate a more specific meaning to it by rewording it. It might now appear as - "If we ignore the obvious daily and seasonal cycles which occur in weather patterns, are there any other cycles which can be used as significant aids to forecasting?". Such a question conjures up different responses from different people. The worshippers at the shrine of the "sun spots-cum-weather" will affirm that there is a weather cycle of about 11 years, the disciples of the "moon and meteorology theory" will vote for the lunar cycle (or some function of it) in weather patterns, while some more sophisticated products of the space age will "spread their bets" among various stars and planets.

This is all very interesting and it does denote a healthy interest in the environment, but in this day and age, we need remain in no doubt as to the validity of the claims of any of the partisan groups. The state of the mathematical art is such that we know how to do the sums which are necessary to test the theories, electronic computers are available to take the drudgery out of the relevant calculations, and most importantly of all, adequate and reliable meteorological records are available for us to test the theories.

In the discussion which follows we will not do the actual sums, but in a descriptive manner we will consider the methods involved, and so help to remove a great deal of the mystery from this rather complicated subject. In addition, we will apply the theory to some typical meteorological data.

2 THE CONCEPT OF A TIME SERIES

Sets of observations which are made at evenly spaced intervals of time, constitute a time-series. Typical examples of time series are given by the set of, say, the 8.30 am temperature recorded each day at Adelaide, or again by its annual rainfall totals. There are a large number of meteorological records which have been maintained unbroken for more than 100 years and so there is no dearth of experimental data in the form of time series.

Generally time series can be divided into the two main classes of (a) deterministic and (b) those containing stochastic or random elements. A deterministic series is one in which the value of future terms can be predicted precisely. If for example we had a series:-

$$x(t) = 2t + 4$$

where x(t) stands for the value of an observation at time t, then we have a deterministic series. This is so, since if we commence with an arbitrary value of t, say t = 1 we have:-

$$x(1) = 2 \times 1 + 4 = 6$$

and at time t = 2, we have:-

$$x(2) = 2 \times 2 + 4 = 8$$

and so on. Then so long as we can allocate a value to the time t, we can put an exact value on the x(t). Meteorological series do not behave in this convenient fashion, but astronomical series do, if not perfectly then very nearly so. This explains why astronomical phenomena, such as eclipses of the sun, can be predicted so precisely so far into the future.

If instead of our deterministic series we had series:-

$x(t) = 2t + e(t)$ or more generally still, $x(t) = at + e(t)$

where e(t) is a perfectly random element and 'a' is any number, then we have a stochastic series. This means that e(t) can vary with each observation, and its values are quite independent of the time the observations were made. This is the type to which meteorological series belong, and the degree of influence of the random element (that is of the e(t)) is an indication of how good or how bad a forecast will be, if it is based solely on past history. In the case which is furthest removed from deterministic, the stochastic element e(t) exerts a major influence, and the series then behaves as a set of random numbers. This means that past history is of no value whatever as an aid to predicting future values.

Our problem then when we are presented with a set of meteorological data, is to calculate whether there is a significant historical or serial relationship within the series, or whether the stochastic content is so strong as to make the series behave as a set of random numbers. An historical relationship may occur in the form of a trend, that is a systematic change with time, or as a cycle, and here we are investigating the phenomenon of cycles.

3 THE METHOD OF ANALYSIS

One method of testing how well past history may be used to assess the reality and value of a cycle as an aid to prediction is to calculate and test values of serial correlations. The correlation between two sets of values occurring in pairs is an indication of how closely one set varies with the other, and by a mathematical device, the value of the index of correlation, (or the correlation coefficient as we call it) can be confined within values of +1.0 and -1.0.

As an example let us assume we have two variable quantities say x(t) and y(t), where x(t) is the reading of a value in the x series at time t, and y(t) is the reading in the y series at the same time t. The x - values, for instance might be annual rainfall totals at Adelaide and the y - values might be annual rainfall totals for the same years at, say Parafield.

If now we found a correlation coefficient of +1.0 and we plotted pairs of values on graph paper, the graph would be as shown in Fig 1.

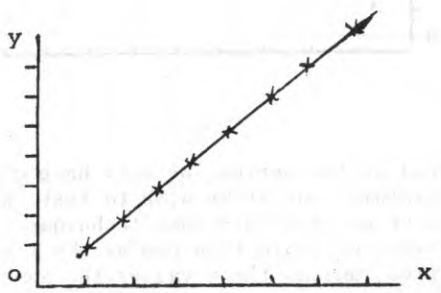


Fig 1

All pairs of values would lie on a straight line sloping upwards from lower left to upper right. This means of course, that increases of x were always associated with increases of y.

If now we had found a correlation of -1.0, this would mean that increases in x were always associated with decreases in y. The resulting graph would be as shown in Fig 2, again with all data points lying on the straight line.

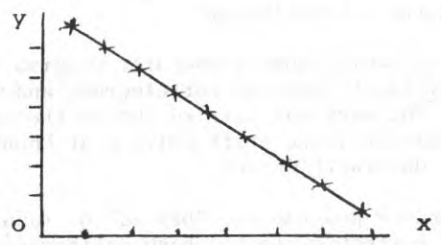


Fig 2

Now if in a third case we found a correlation of 0.0, the pairs of values would show no regular pattern at all, and the resulting graph would be as in Fig 3.

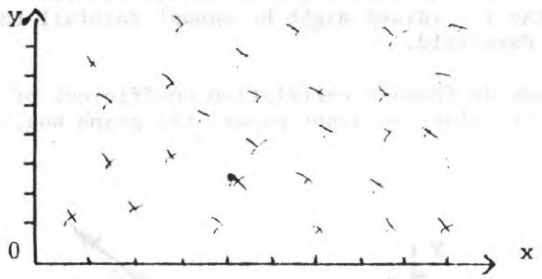


Fig 3

If instead of two series, we only have one set of data, say Adelaide annual rainfall, and if we wish to test, whether there is, say a five year cycle, we can use this same technique. Instead of an x series and a y series, we could then use as the x values the Adelaide data as they occurred, and as the y values the same data, but "lagged" by five years. This means we would correlate the value recorded in 1900 (the x) with the value recorded in 1905 (the y), the value recorded in 1901 (the x) with the value recorded in 1906 (the y), and so on through the entire series. Then if the correlation coefficient was found to be positive and significantly different from 0.0, we would say these appeared to be an oscillatory or cyclic tendency with a period of 5. This means in effect that a large value would tend to be followed five years later by a large value, and similarly a low value would tend to be followed five years later by a low value, and the 'goodness of fit' would depend on how closely the correlation value was to the limiting value of 1.0.

In fact of course we would not generally know what periodicity we were looking for, so we would calculate the correlations with different lags, say 1, 2, 3, - - and so on. For convenience we draw the graph of these correlations which we call lag correlations, and we call the resulting diagram a correlogram.

In writing this paper a computer program has been prepared to calculate the individual terms of correlograms and then to plot the relevant values. The work was carried out on the computer terminal at the Australian Administrative Staff College at Mount Eliza, Victoria. The computer is a Honeywell-GE 265.

The computer program was "proved" by running it with a test series in which a perfect cycle had been deliberately built in. This was done by using a set of 100 numbers in which each term was repeated exactly after 10 terms.

The computer output showing the resulting correlogram is shown in Fig 4. Note that the lag correlation scale is across the page and it ranges from -1 to +1, while the actual values of the lag correlations are shown with the value of the lag plotted on the point. Note also that the correlation with lag 0 is always exactly equal to 1.0, since this is the correlation between two sets of identical values, that is the correlation of a series with itself, and so there is a "perfect fit".

Above the graph, the computer output shows a tabulation of the values of the lags and the relevant serial correlations. A word of explanation may be necessary with regard to the notation. In example at lag 2, we see the serial correlation appears as 7.12934 E-02. This is how a small number is printed by the computer. It means 7.12934/100 or 0.0712934. The number of zeros in the divisor is given by the figure appearing after "E-", and so if the figure had been E-03 we would have divided by 1000.

In this particular diagram the correlation at lag 10 is also 1.0, and this shows the perfect cycle of lag 10 which had been 'built in' to the test series.

As a contrast, and to demonstrate the other extreme, Fig 5 shows the same computer program run with a set of 100 random numbers. Now it can be seen that the lag correlation values are grouped around the zero line. The random numbers were also generated with a 'built in' computer program, and it is interesting that just as we can use the correlogram to test for periodicity in a time series, so we can also use it to test for true randomness in a random number series, since in this second case there should be no periodicity in the series. In fact the small 'wave' which shows in Fig 5 does raise some doubt as to the efficiency of the random number generator supplied with the computer, the doubt being that the sequence may not be truly random.

4 AN EXAMINATION OF SOME RAINFALL DATA

After the correctness of the correlogram program had been proved by applying it to the cyclic series and also to the set of random numbers, it was used to test for periodicities in the annual rainfall totals recorded in Adelaide for the period 1861 to 1970. The resulting output of the computer program appears in Fig 6.

As before, the value of the correlation at lag 0 is 1.0, but it will be seen that all other correlation values are very nearly zero. Note in the table at the top of the graph that the serial correlation with lag 3 is -8.57627 E-03, that is a value of -8.57627/1000 or -0.00857627, and so on the graph we see this as a very small number on the negative side of the zero line.

The value of the serial correlation at lag 14 is .141552. This is the highest value appearing in the correlogram. A mathematical test would show that a value of at least .2 (either plus or minus) would be needed before a correlation coefficient could be classed as significantly different from zero. Even a value higher than this might occur by chance and so we cannot logically study a correlogram then deliberately select the highest value, and then say we have a real periodicity at that value of lag.

To demonstrate the logic involved in this point let us use the analogy of a man tossing 10 one cent pieces, and let us assume he repeats the process, say 100 times. Obviously there are many possible outcomes from each throw. He might, for instance, throw 10 heads, or 9 heads and 1 tail, or 8 heads and 2 tails, and so on down to 10 tails. Intuitively we would expect 5 heads and 5 tails to occur most frequently, and in fact the probability of throwing 10 heads (or 10 tails) is $(\frac{1}{2})^{10}$ or one in one thousand and twenty four. While this is a very small

probability the 10 heads can occur, and in fact should occur on the average, once in about every thousand trials. Now say our thrower actually did find 10 heads on the 43rd throw, and after the completion of the 100 throws he claimed that he could throw 10 heads on the 43rd throw in every 100 throws. We would be entitled to be highly sceptical. If on the other hand, he had made his claim before he started throwing, or better still, if he could successfully repeat the experiment, then we would have to examine his claims more critically. Incidentally if he could establish that he could perform this feat, we would say that a non-random influence was involved.

So it is with apparent periodicities which may occur in series such as rainfalls. We could simulate repeating the experiment by dividing the data up into two halves, and then test whether the correlogram peaks occur at the same lag point for each of the sub-series. Alternatively we could use data from another station and compute that correlogram, also. The selection of the other station would need to be made carefully. We are trying to identify what we might call a "meteorological fluke", and so if the two stations are so close to each other that such a "fluke" at one must necessarily have occurred at the other, then obviously our testing is still not valid. For example if the two stations were so close that their rainfalls were identical, then testing data from both would be wasteful and of no practical use.

All this highlights the need to spell out precisely just what we are testing. If we are trying to establish whether there is a cyclic tendency in annual rainfalls in the general area of Adelaide, then we should be justified in using the records from Strathalbyn as the second or 'control' station. This station was selected for test here, firstly because it was far enough from Adelaide to ensure the rainfalls were not identical, and also because a long record was available.

The correlogram of Strathalbyn annual rainfalls for the period 1861-1970 appears in Fig 7. As in the case of the Adelaide data, the maximum value of this correlogram occurs at lag 14. The value of approximately .25 can be shown to occur by chance on less than 5% of occasions, that is on fewer than 5 trials in every 100. The claim that this represents a real periodicity is valid, as in the case of the coin tossing, only if we had pre-nominated that we were going to test the value at lag 14. It cannot be stressed too strongly that we cannot logically select the peak values after the graph is drawn, and then test them to see if they are different from zero.

From the combined evidence of the Adelaide and Strathalbyn graphs there is some evidence for the existence of very weak oscillation in annual rainfalls at lag 14, and the next obvious question is "how weak is it?"; or rather, we are more interested in "how strong is it?".

For the purpose of this part of the exercise let us assume that we have established the reality of the cycle at lag 14, that is, we have established that it will stand up to the test of appearing in the correlograms of data from other stations in the same general area. Then what we really want to know is - "By how much can we improve our forecasts if we can use a correlation of 0.25 at lag 14?".

In the first place we can see from the correlograms that this could only have a bearing on values occurring with a period of 14 years. Further, by the use of some more mathematics, it can be shown that a

correlation as small as this will have an extremely small effect. Thus it can be shown that the effect varies as the square of the correlation, and so writing the correlation of 0.25 as ¼, the effect varies as ¼ squared, that is as 1/16. This means, that of all the variation of the annual rainfalls at Strathalbyn the "14 year cycle" accounts for 1/16 or about 6% and so leaves unexplained 15/16, or about 94%. An effect as small as 1/16 would not be perceptible, and could only be detected by recourse to mathematics. For immediate practical purposes then we could say it was of no value.

As a contrast, note how in our test series with the built-in periodicity, we had a correlation of 1.0 at lag 10. This means that we could account for all the variation by the "10 period cycle" and so we could predict the series precisely.

Despite the fact that, if this tendency to oscillate is real, it is of no immediate value to forecasters, we should not "throw away" results like this. A correlation as small as 0.25 might be of immense assistance to research workers, in that it might well hold the key to some secrets of general weather systems, and in this way lead to a subsequent improvement in forecasting techniques. Note that we stipulated above that it was of no immediate practical assistance.

In this connection, Fig 8 shows the correlogram of June rainfall totals at Hobart for the period 1883-1969. There appears evidence that there is a definite though weak oscillation every seven years. This means of course, that there is a tendency for June rainfall in any year in Hobart to be repeated after seven years. Again the tendency is weak, the correlation of about 0.3 accounting for only about $(0.3)^2$, that is 0.09 or about 9% of the total variation.

As in the case of the Adelaide and Strathalbyn annual rainfalls, these correlations of June rainfalls at Hobart cannot be used for forecasting, but in some other research, they have been used to study an apparent regularity in atmospheric circulation patterns of the southern oceans.

5 CONCLUSIONS

From this short study we can arrive at the general conclusion that there is no evidence at present to say that any weather cycles are known to occur in sufficient strength or with sufficient regularity to be of immediate help to forecasters.

In the terms of correlation theory as we have looked at it, we can say we would need a correlation value of about 0.7 to make a practical impact on the problem. Such a correlation would account for about half the total variation, since $(0.7)^2 = 0.49$ that is very nearly 0.5 or 50%. Any factor which does not account for about 50% of the variation can hardly be classed as being of significant value when treated alone.

Despite this apparently disappointing statement, it is to be hoped that research will continue in this general field, so that more and more secrets of weather systems may become known to us. The work is onerous, and as in the case of most other forms of research, a spectacular breakthrough is not likely to occur. All that can be expected is a very gradual extension of the bounds of human knowledge as a result of many man-years of investigation.

PROGRAM TO CALCULATE SERIAL CORRELATIONS WITH LAG K WHERE K RANGES FROM 0 TO 15. THE PROGRAM ALSO DRAWS THE CORRELOGRAM.

(TEST DATA OF 100 NUMBERS WITH A PERIODICITY OF LENGTH 10.)

LAG	SERIAL CORRELATION	LAG	SERIAL CORRELATION
0	1.	8	-.011613
1	.491146	9	.415920
2	.071293	10	1.
3	-.241971	11	.495327
4	-.438776	12	.076056
5	-.515152	13	-.238266
6	-.470325	14	-.436921
7	-.30368	15	-.5.5152

GRAPH OF CORRELATION

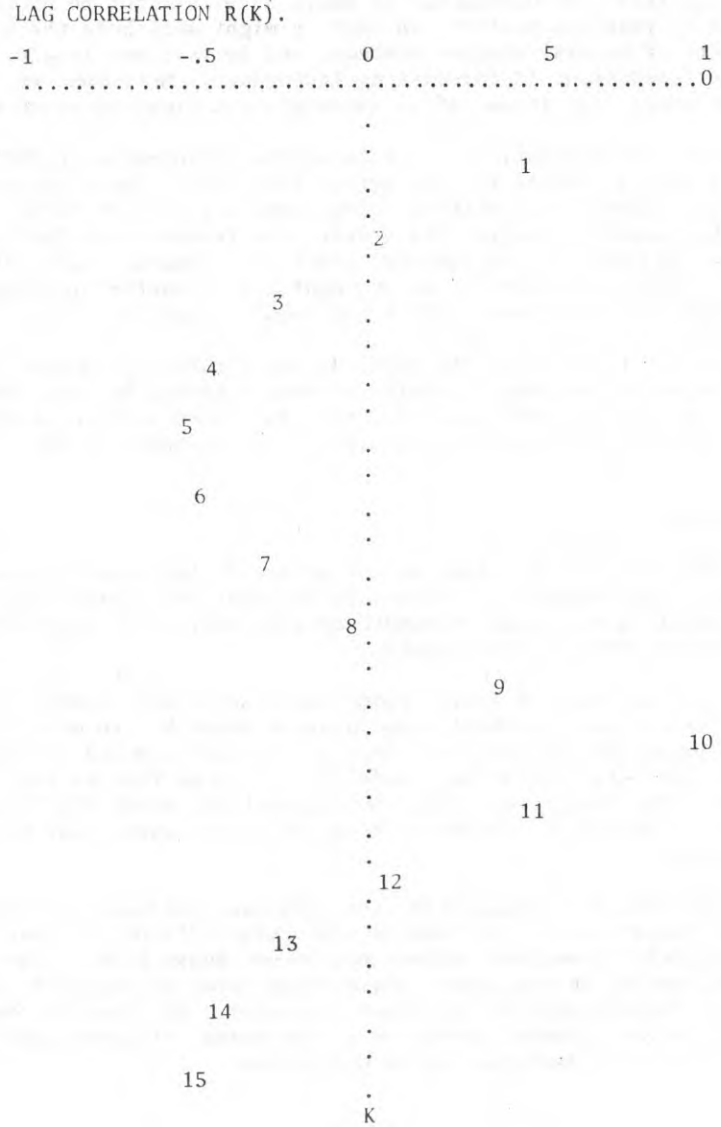


Fig 4

PROGRAM TO CALCULATE SERIAL CORRELATIONS WITH LAG K WHERE K RANGES FROM 0 to 15. THE PROGRAM ALSO DRAWS THE CORRELOGRAM. (TEST DATA OF 100 NUMBERS WITH A PERIODICITY OF LENGTH 10.)

LAG	SERIAL CORRELATION	LAG	SERIAL CORRELATION
0	1.0000	8	-.0116
	.4911	9	.4159
2	.0713	10	1.0000
3	-.2420	11	.4953
4	-.4388	12	.0761
5	-.5152	13	-.2384
6	-.4703	14	-.4369
7	-.3037	15	-.5152

GRAPH OF CORRELATION

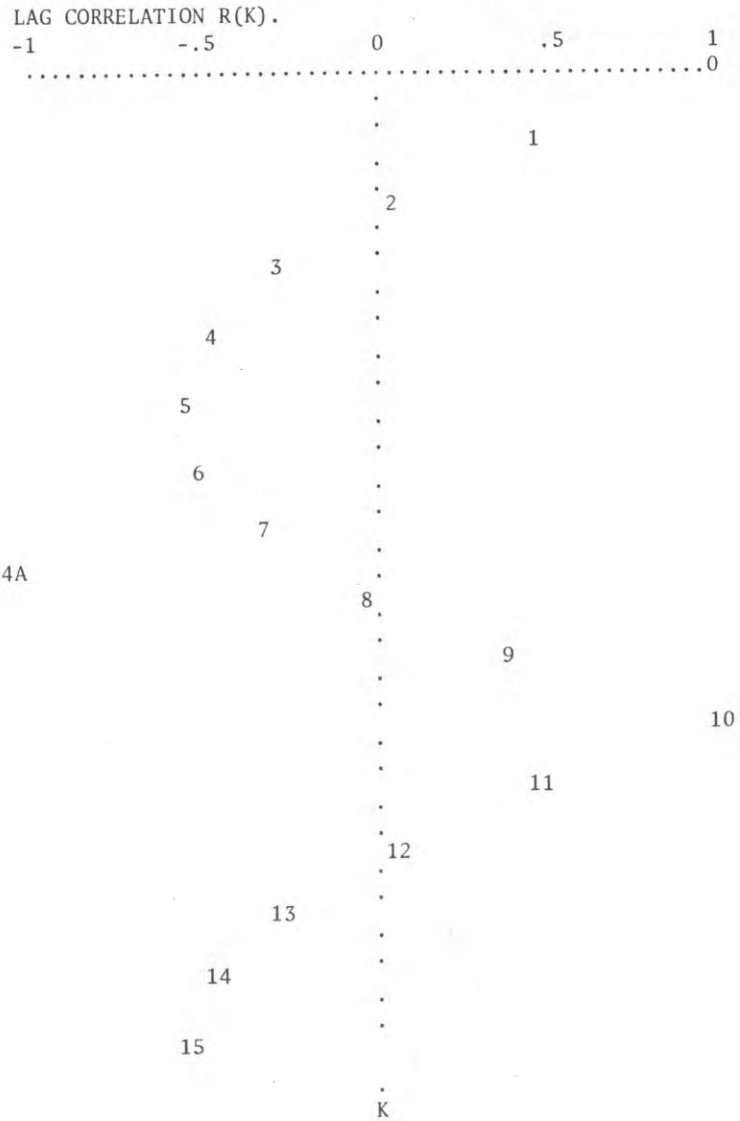


Fig 4A

PROGRAM TO CALCULATE SERIAL CORRELATIONS WITH LAG K WHERE K RANGES FROM 0 TO 15. THE PROGRAM ALSO DRAWS THE CORRELOGRAM.

(TEST OF DATA OF 100 RANDOM NUMBERS)

LAG	SERIAL CORRELATION	LAG	SERIAL CORRELATION
0	1.0000	8	-.0212
1	-.0235	9	-.0087
2	-.0263	10	-.1644
3	.0153	11	-.1572
4	-.0357	12	.0017
5	-.0345	13	-.0041
6	.1441	14	-.0058
7	- 0826	15	.0670

GRAPH OF CORRELOGRAM

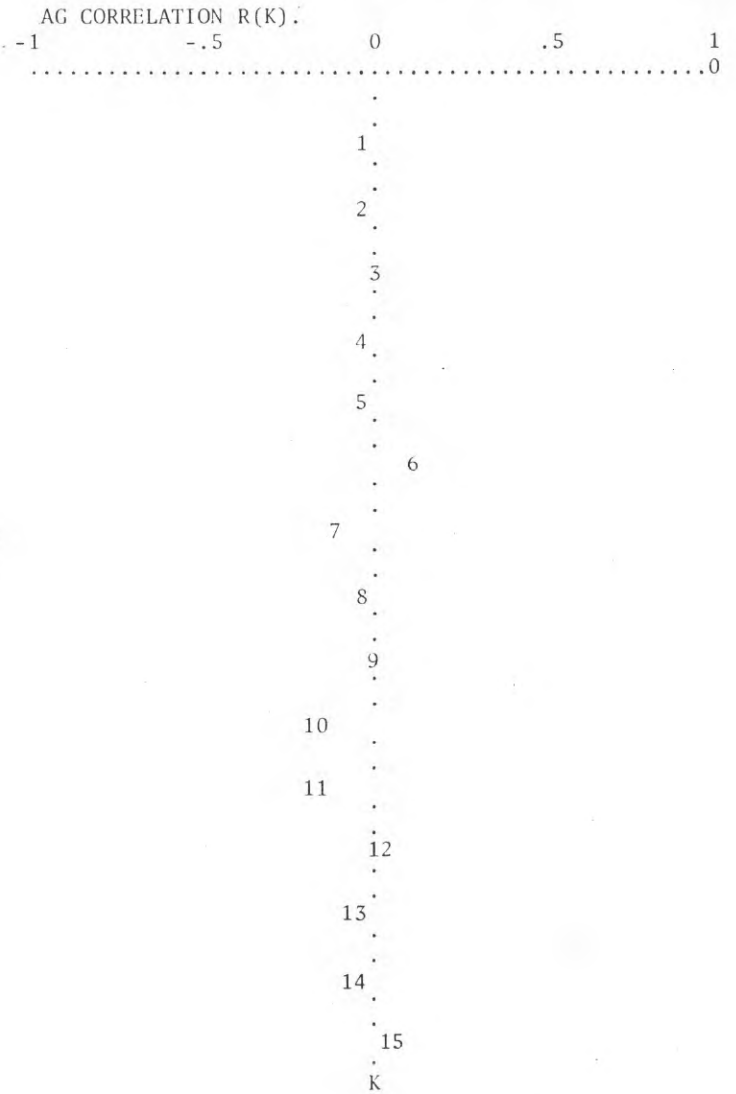


Fig 5

PROGRAM TO CALCULATE SERIAL CORRELATIONS WITH LAG K WHERE K RANGES FROM 0 TO 15. THE PROGRAM ALSO DRAWS THE CORRELOGRAM.

DATA USED ARE 110 YEARS OF ANNUAL RAINFALL AT ADELAIDE FOR THE PERIOD 1861 TO 1970

LAG	SERIAL CORRELATION	LAG	SERIAL CORRELATION
0	1.0000	8	-.0134
1	-.0587	9	-.0219
2	-.0709	10	-.0229
3	-.0086	11	-.0454
4	-.0422	12	.0465
5	.0210	13	-.0605
6	-.0103	14	.1416
7	-.0418	15	.0916

GRAPH OF CORRELOGRAM

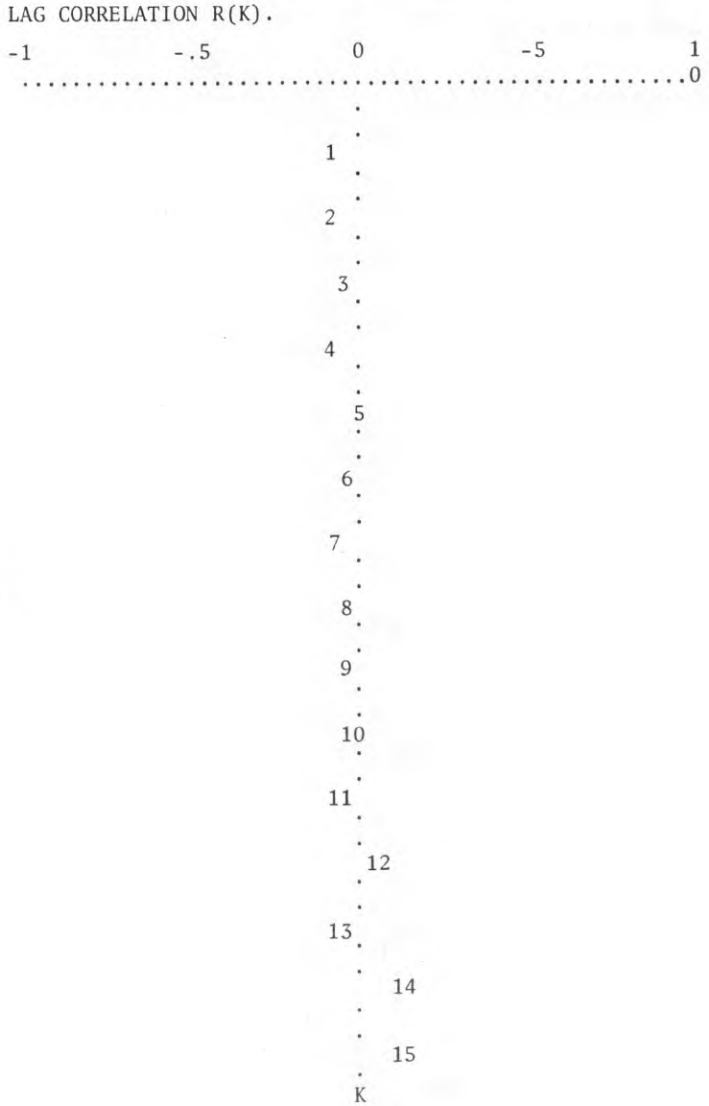


Fig 6

PROGRAM TO CALCULATE SERIAL CORRELATIONS WITH LAG K WHERE K RANGES FROM 0 TO 15. THE PROGRAM ALSO DRAWS THE CORRELOGRAM.

DATA USED ARE 110 YEARS OF ANNUAL RAINFALL AT STRATHALBYN FOR THE PERIOD 1861-1970

LAG	SERIAL CORRELATION	LAG	SERIAL CORRELATION
0	1.0000	8	-.0027
1	-.0534	9	-.0050
2	-.0021	10	-.0150
3	-.0302	11	-.0817
4	.0378	12	-.0263
5	.0122	13	.0624
6	-.0372	14	.2464
7	-.0605	15	-.0416

GRAPH OF CORRELOGRAM

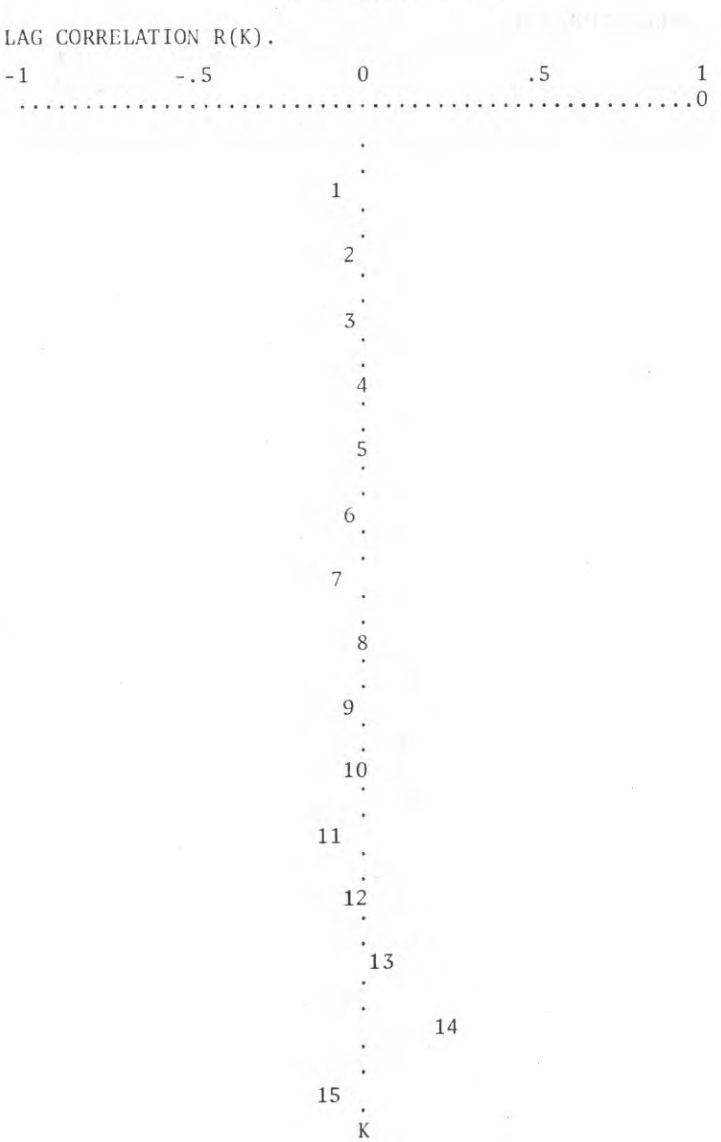


Fig 7

PROGRAM TO CALCULATE SERIAL CORRELATIONS WITH LAG K WHERE K RANGES FROM 0 TO 15. THE PROGRAM ALSO DRAWS THE CORRELOGRAM.

DATA USED ARE 87 VALUES OF JUNE RAINFALL TOTALS FOR HOBART FOR THE PERIOD 1883-1969

LAG	SERIAL CORRELATION	LAG	SERIAL CORRELATION
0	1.0000	8	.1162
1	.1426	9	.0124
2	.0382	10	-.1273
3	-.1249	11	-.2454
4	-.1849	12	-.2134
5	-.1333	13	-.0929
6	.0010	14	.0317
7	.2923	15	.0183

GRAPH OF CORRELOGRAM

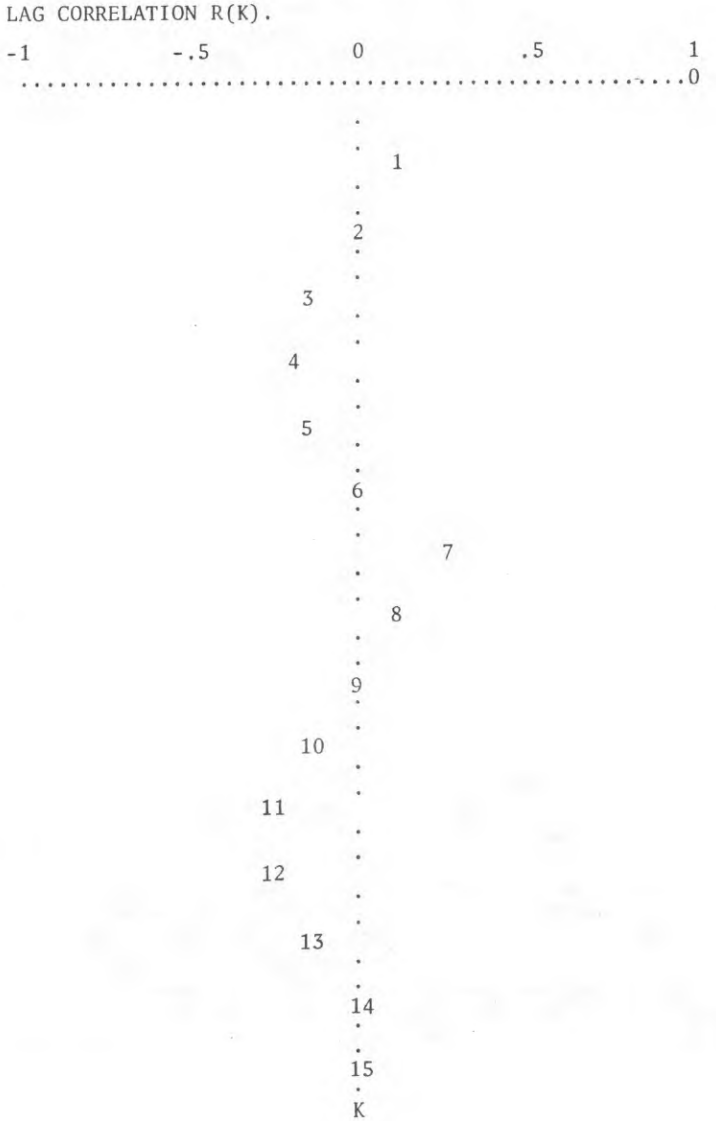


Fig 8

WEATHER ROUTEING PROCEDURES IN THE UNITED STATES

by George W. Francis

(Supervisor, OTSR Division, Fleet Weather Central Norfolk, Virginia)

INTRODUCTION

American weather routeing started about 200 years ago. In 1769 Dr. Benjamin Franklin, the Deputy Postmaster-General of His Majesty's colonies in North America, wrote to Anthony Todd of the British Post Office suggesting routes for the masters of the sailing packets to use to speed the mail service between England and America. These route recommendations were based on observations of the Gulf Stream supplied by Franklin's Massachusetts whalingmaster kinsman.

This paper will show briefly the development of weather routeing in the United States and experience in the Atlantic area. It will expand somewhat the material on weather routeing activity in the United States which was presented to an informal meeting of the Honourable Company of Master Mariners in London in 1966. That paper, which appeared in The Marine Observer in 1967 entitled "Practical Results of Weather Routeing", was prepared by Captain W.E. Cummins, USN Commanding Officer, Military Sea Transportation Service Office, London, from material supplied by US Fleet Weather Central Norfolk, Virginia.

The term 'weather routeing' is not limited to weather as such, but is understood to mean the total oceanic environment as it affects the safety and efficiency of merchant and naval shipping.

WEATHER SERVICES ORGANIZATION

It is important to emphasize that weather services in the United States are a function of both government and private enterprise. The Environmental Science Services Administration, Weather Bureau, US Department of Commerce has the responsibility for collecting and analysing the basic meteorological data and making it available to all who wish to use it for whatever useful purpose. The Weather Bureau is also responsible for issuing general storm warnings and forecasts for the United States as a whole. Specialized meteorological service for individuals and corporations is provided by private meteorological organizations where available, and the Air Weather Service and the Naval Weather Service Command provide a weather service tailored to the special needs of the military services. Thus, any specialized weather service is dependent on the National Weather Service for much of its working data.

DEVELOPMENT OF WEATHER ROUTEING

Commercial weather routeing in the United States was initiated by Louis Allen on the east coast and Howard Kastner on the west coast in the early 1950s. It was developed to serve individual shipping lines and/or marine associations on a ship-by-ship basis. This operation has grown so that there are now some seven private weather service corporations and weather consultants engaged in providing specialized forecasts to the merchant marine, both domestic and foreign, in the Atlantic area. Weather routeing for the ships under the operational control of the US Navy was developed by Dr. R.W. James of the Naval Hydrographic Office, beginning in about 1954, and became operational in the Naval Weather Service in 1958. Optimum Track Ship Routeing (OTSR)

service for all types of United States fleet shipping and for the Military Sea Transportation Service (MSTS) is now provided in the Atlantic by US Fleet Weather Central Norfolk, and in the Pacific by US Fleet Weather Centrals Alameda and Guam. This Naval weather-routeing service is also provided to about 20% of US merchant marine ships while under time charter to MSTS.

GENERAL PROCEDURES

All weather routeing in the United States, whether provided by private enterprise or the Naval Weather Service Command, appears to operate on essentially the same principles and uses similar methods. All organizations consider that weather routeing is primarily meteorological in their approach to the environmental problems of safe and efficient navigation. Route recommendations for the entire passage are sent prior to departure, in response to a specific request from an individual master or commanding officer or from an operating agency. This request spells out the transit problem in detail, including speed available, draught fore and aft, deck loading and any unusual stability problems. The routeing agencies encourage the user to set priorities and state the problem as completely as possible. Some make a point of frequent personal liaison with the user to learn his point of view and desires.

Once the original route recommendation has been sent, all weather routeing organizations maintain a continuing watch on the progress of the ship during the passage and send route-change recommendations as necessary to give the environmental conditions desired. Allen Weather Corporation sends a confirmation of the original route or a change recommendation at three to four-day intervals but, at least in the Atlantic area, daily routeing messages are not sent by any of the routeing organizations. About 65% of all the routeings supplied by US Fleet Weather Central Norfolk are steamed without further recommendations. The other 35% receive one or more route-change recommendations for a number of reasons, including such non-environmental ones as change in destination.

ROUTE SELECTION

The selection of the original recommended route is essentially a subjective process based on modern meteorological and oceanographic knowledge and much ship-routeing experience.

Basic to route selection is a detailed statement of operational requirements and priorities. These can be stated in the route request, in general operation policy directives, or through personal liaison with either afloat or shore-side operating department personnel. The users' priority decisions concerning least-time versus damage risk, environmental requirements for under-way replenishment, air operations, underway training and maintenance, or need to protect sea-sensitive deck cargo, must all be known by the ship-router. The standard practices of good seamanship, good positional navigation and techniques to avoid icebergs must be applied to route selection. American ship-routers feel that while ocean currents are significant to some passages, the primary environmental element affecting ship speed is the wave field. Towing-tank experiments with model ships in model waves show that effective wave resistance should result in a speed reduction of only about 14% in high head seas. However, ship log data show that ships regularly slow to bare steerage way in these conditions. This slowing is really the

result of a subjective estimate by the mariner of what speed the ship can do without unacceptable damage risk. The familiar James ship-performance curves are thus the average thinking of the whole group of mariners about how their ships perform in various, not too well-defined, wave fields. American weather routeing offices rely on the wave spectrum methods of Pearson, Neuman and James and the earlier work of Sverdrup, Munk and Bretschneider, in understanding wind waves.

Automated solutions to the weather-routeing problem are under active development at this time. Some organizations are using computers as bookkeeping tools in the route-following portion of the total operation. Computer programmes have been written and successfully tested which will compute a least-time track given the necessary environmental fields. However, skilful eight to ten-day forecasts of the wave field are not yet available.

American ship-routers do show skill in the selection of the general path of the low centres. This path is called the "storm track". They can model the maximum wave-height areas associated with the lows. Then, knowing the general areas of higher waves, they can select routes to minimize time in these areas. These routes will, in general, be the best available routes.

STORM-TRACK ESTIMATE

A number of ideas are used in the storm-track estimate. The original American weather-routeing scheme used the five-day extended forecast charts of the Weather Bureau to estimate storm tracks and build waves. These were based on mean 700-mb height anomalies and anologues. Recently the extended forecast charts have been issued daily. They are now based in part on an extended run to the primitive equation multi-level numerical forecast programme at the National Meteorological Center, Environmental Science Services Administration, Weather Bureau. This is a useful tool but still does not extend far enough. At US Fleet Weather Central Norfolk we use this tool and a mixture of other concepts. Basic to our practice is the concept that there is an identifiable "witterung" or weather regime to the 500-mb flow pattern and that surface systems are steered and governed by this 500-mb flow pattern. We recognize that major surface developments occurring near or east of continental break points, such as the Rocky Mountains and the Greenland peninsula, and those areas of strong surface temperature contrast, such as the continental coast lines in winter and the north wall of the Gulf Stream, may strongly influence the 500-mb flow pattern.

The 72-hour 500-mb forecast, skilfully forecast by the digital computer, shows the conservation major steering elements of this pattern. C.G. Rossby's long-wave concepts are a powerful tool for evaluating the 500-mb flow and extending this forecast. The pattern-separation techniques of US Fleet Numerical Weather Central, Monterey, California, are used to find the long waves. This computer system uses a 500-mb space mean combined with a climatological monthly mean to find the long-wave disturbance pattern. When this is compared with the preceding series of 500-mb space mean charts, the position and motion of the long waves may be found. A gross zonal wind computation, using a nomogram by C.V. Smith of the British Meteorological Office, gives the stable long-wave length. This is compared with the actual long-wave length to anticipate a change in wave number. CAVT trajectories are used at likely points to further evaluate areas of suspected pattern change. The group velocity concept is used to extrapolate the energy of

rapidly-developing large-scale disturbances from the Pacific into the Atlantic area as an aid in timing pattern changes.

The storm-track estimate follows the long-wave estimate. A study of five-day storm positions plotted on a 500-mb space mean chart for the middle day of the series during several months of the past winter shows a strong qualitative correlation between the storm track and the 500-mb mean flow. The correlation is strongest in blocking situations but is also moderately strong in more zonal situations. Using the well-known principle that surface lows intensify between the long-wave trough and the next downstream ridge, and weaken from ridge to trough, a good subjective estimate of strong wind areas and hence likely very rough to high seas areas may be made. These estimates are combined with a knowledge of storm-track, wind and wave climatology and an understanding of the needs of the routed unit to select and recommend an optimum track.

Satellite pictures transmitted by facsimile from the National Environmental Satellite Center via the National Meteorological Center are used by most weather routeing offices to aid analysis in sparse data areas such as the South Atlantic and high latitudes in the North Atlantic. These satellite pictures play an important part in the shorter-range daily-route evaluation process.

COMMUNICATIONS

Original route recommendations are sent via the most practical means, frequently to the operating headquarters for further delivery to the ship. Route-change recommendations to improve the route after the ship is under way go direct from the weather-routeing office to the ship by the fastest means and not through the operating headquarters. This is usually commercial radio for merchant ships and naval radio for MSTS dry-cargo shipping and fleet units.

SERVICE EVALUATION

How successful has the operation been? The best testimony on that question is the continued steady growth of the acceptance of the services available and the growth in number of organizations from two to seven which provide service. US Fleet Weather Central Norfolk has provided over 8,000 route recommendations to MSTS and fleet ships and units operating in the Atlantic since 1958, and provided 855 route recommendations in the year ending 30 June, 1970.

Quantitative evaluation of the service rendered is difficult. The basic question is, "Are routes recommended by shore specialists better than routes selected in the ship and are they significantly better to pay for the service?"

Private ship-routeing organizations have applied two different concepts to route evaluation. Weather Routing Incorporated has used the concept of time used on a recommended route compared with computed time required in flat water on an arbitrarily defined standard route. Standard route is defined as the average time EN ROUTE for all non-routed ships in the same class, in the same trade, between two longitudes serving as junction points, in the approaches to frequently used terminals. These non-routed ships may be those electing to ignore route recommendations, or the recorded data for ships in the trade operating before the routeing service began. Comparing the experience of routed ships with this standard clearly indicates an average saving of six to twelve hours for Atlantic crossings between the mid-Atlantic coast of

the United States and North-West Europe. The larger savings are likely on the westbound crossings. Bendix Commercial Service Corporation has considered the shortest, safe, navigable distance between ports divided by the ship's rated speed in her loaded condition as the time for 100% efficiency. This time is compared with the actual steaming time to compute actual efficiency. When routed-ship efficiency is compared with that of non-routed ships of the same class and trade, their study shows that routed units average 6-12% more efficient than non-routed units.

In the development of the Navy weather-routeing programme the Naval Hydrographic Office and MSTS carried out several classic experiments comparing the performance of two similarly loaded victory ships departing from the same point at the same time for the same destination. The opportunity for similar comparisons has occured only by chance and rather infrequently since then. In the relatively few cases on record, the ship steaming on the weather-routed track has usually arrived days ahead of the ship using some other track. In those isolated cases when the two ships have arrived together, the routed ship has never been more than four hours behind the non-routed ship.

The most sophisticated route-selection evaluation tried in the United States used the digital computer least-time track programme and wave fields analysed from daily ship reports to compute after-the-fact least-time tracks. These tracks were compared with those selected subjectively before-the-fact and steamed by the real ship. It was expected that the computer tracks based on history rather than forecasts would be the best available least-time track. Results showed that the computer did give a least-time track, assuming that the ship-performance curves were valid. However, these tracks were not necessarily optimum from a damage-risk consideration nor would they have always been acceptable by a prudent master. These comparisons also showed that the trained ship-router could subjectively do nearly as well selecting tracks to minimize time and, simultaneously, minimize damage risk.

Damage experience indicates that it is possible to reduce damage to a minimum using weather routeing. US Fleet Weather Central Norfolk has had a damage experience which is inversely proportional to the experience of the ship-routeing staff. The percentage number of routed ships reporting damage has fallen from 2.9% in fiscal year 1963 with mostly new personnel to 0.6% in fiscal year 1970 with a very experienced staff.

Finally, let us assume the average ship-router issues 180 route recommendations a year. Assume the average master works 10 months a year and that he makes an Atlantic crossing every 15 days, or 20 times a year. It would then take 9 years for this fictitious master to accumulate the route selection and evaluation experience achieved by the ship-router in just one year.

Weather routeing works - because the Master, the weather-router and the National Weather Service co-operate, each in his particular area of special competence. They combine their talents and resources to use effectively modern meteorology and oceanography to solve the age-old problem of safe and efficient open-ocean navigation.

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